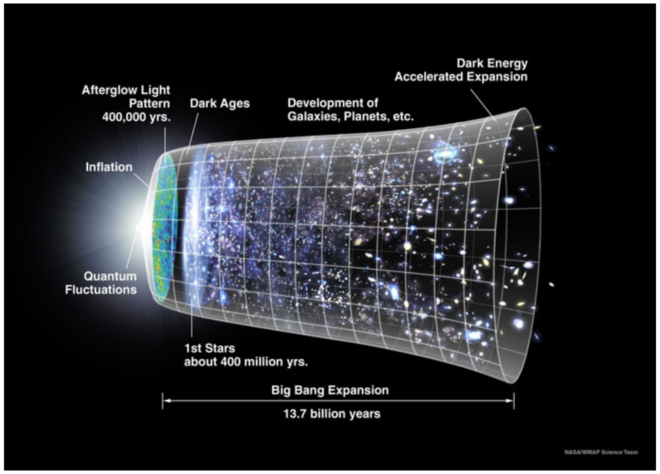
JDEM-Omega Overview

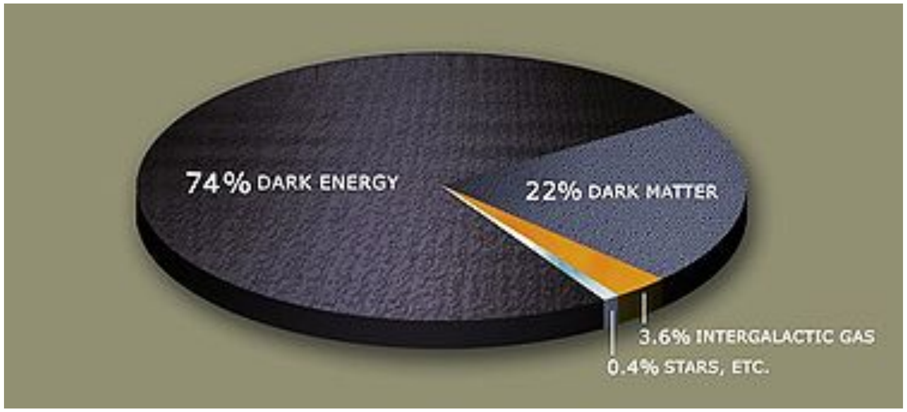
Neil Gehrels, WFIRST Project Scientist

February 3, 2011

JDEM-Omega Science

- JDEM-Omega is a space mission to determine the nature of the dark energy that is driving the current accelerated expansion of the universe
- Profound implications of Dark Energy study on understanding the universe:
  - Universe density (DE is 74% of the mass-energy density)
  - Existence of cosmological constant
  - Signal of new gravitational physics
  - Relation to the accelerated expansion during inflation
  - Relation to dark matter & neutrino mass
  - Connections to superstring theories & extra dimensions
  - Fate of the universe





JDEM History & Timeline

1998-99: Discovery via SN Ia that expansion of space is accelerating

2003: Quarks to Cosmos (Turner) study highlights importance of understanding DE and endorses a space-based mission

2005-6: Multi-agency IWG and DETF panels recommended joint NASA/DOE JDEM mission

2007: NRC BEPAC committee commissioned by NASA & DOE reviews ADEPT, DESTINY & SNAP and recommends JDEM as first Beyond Einstein mission to fly

2008: JDEM formulated as a strategic agency-led mission

2008: Figure of Merit Science Working Group

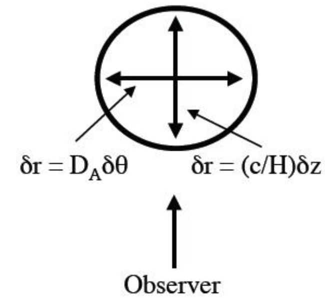
2008: Science Coordination Group (SCG) determined mission requirements

2009: JDEM-DECS & JDEM-Omega presented to Astro2010

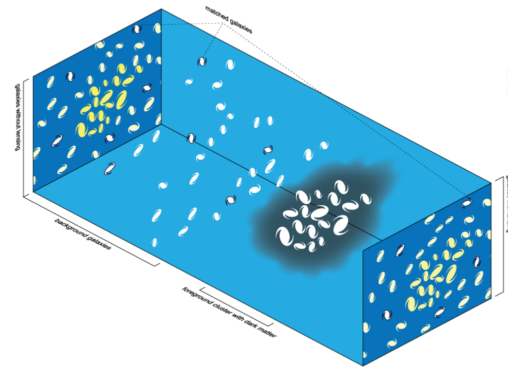
2010: Interim Science Working Group (ISWG) studied low-cost Probe implementations

Measurement Techniques

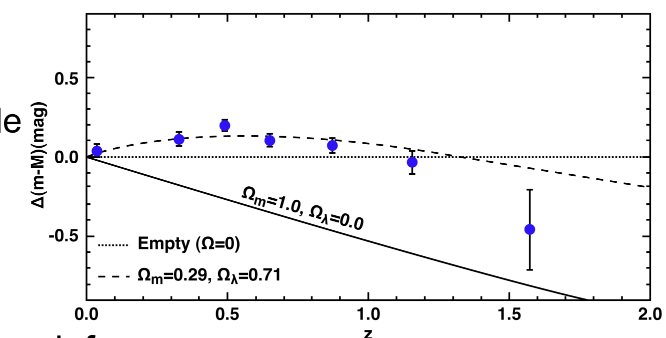
- Three most promising techniques each provide different physical observables and unique information:
  - Baryon Acoustic Oscillation (BAO)
    - $D_A(z)$, $H(z)$ direct measure
    - Emission line galaxies positioned in 3D using strong Hα line
    - Spectroscopic redshift survey in NIR
    - Slitless spectroscopic redshifts



  - Weak Lensing (WL)
    - $D_A(z)$, growth of structure
    - Precision shape measurement of galaxy shapes
    - Photo-z redshifts



  - Type Ia Supernovae (SNe)
    - $D_L(z)$
    - Type Ia supernovae detected into NIR
    - Color and lightcurve parameters for standard candles
    - Clean, uniform measurements with low systematics possible



- Redshift Space Distortions (RSD)
  - Not included in JDEM-Omega RFI response
  - Distortions in Hubble flow due to cosmic structure
  - Galaxy redshifts from BAO survey can give growth of structure info

Advantage of Space

- Precision measurements of dark energy probes are necessarily systematics limited

- Space provides
  - broadband NIR coverage
  - no blur from atmospheric scintillations
  - accessibility of low background sky regions
  - stable systematics control at L2
  - full sky available over 6 months
  - precise repetition of measurements

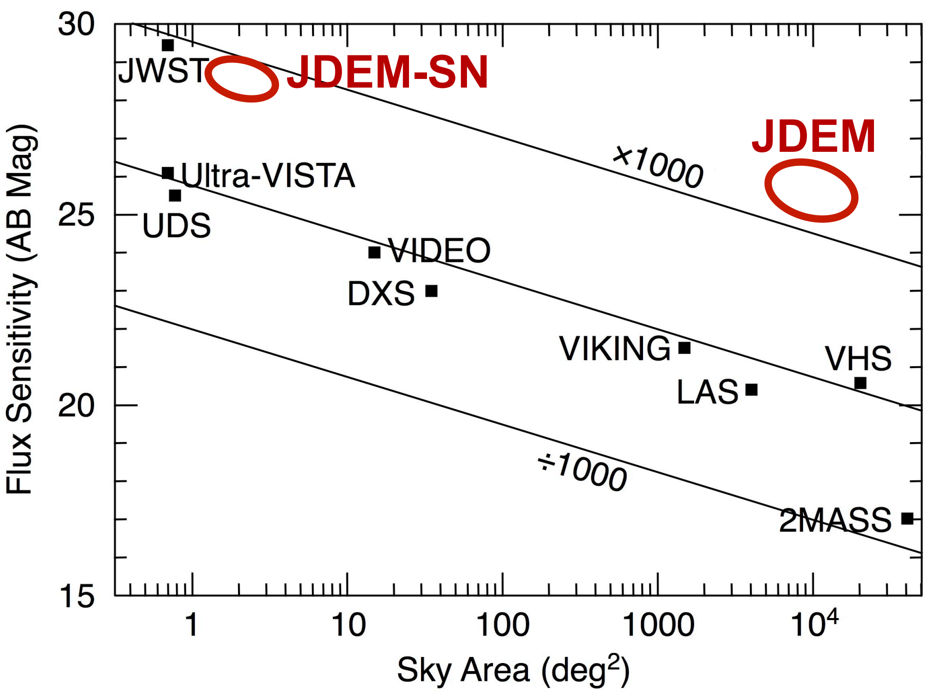
- JDEM-Omega focuses on space-unique capabilities that are complementary with the ground

Ancillary Science

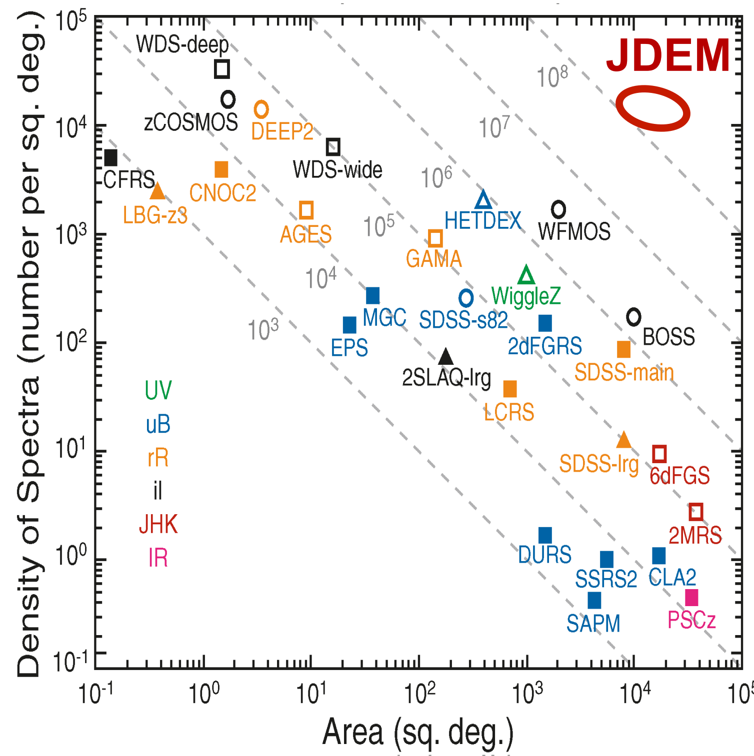
- Large area BAO and WL surveys will be a legacy of JDEM-Omega
- ~100 million galaxies will be mapped in 3D
- Large NIR sky survey will be a boon for ancillary science
  - large-scale structure
  - galaxy clusters
  - high redshift AGN
  - galaxy evolution/structure/formation
  - stellar populations
  - star formation history
  - solar system objects

JDEM-Omega NIR Surveys

NIR Imaging Surveys



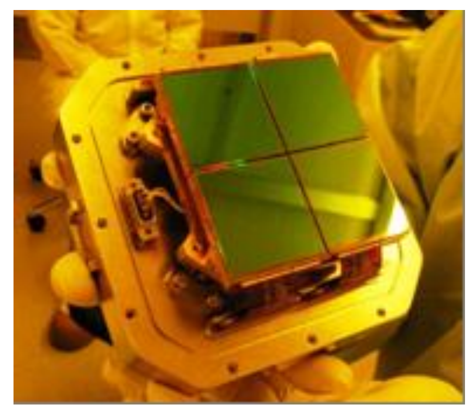
NIR Redshift Surveys



JDEM-Omega provides a factor of 100 improvement in IR surveys

Technologies & Readiness

- Enabling technologies
  - Large format HgCdTe detectors
  - Wide-field broad-band diffraction-limited telescopes
  - High-speed processors with large data storage
- Diffraction-limited sensitive wide-field sky coverage in NIR available for first time
- All JDEM-Omega technologies are high Technology Readiness Level (TRL) and ready-to-go
  - Heritage from HST, JWST
- JDEM-Omega can be built today

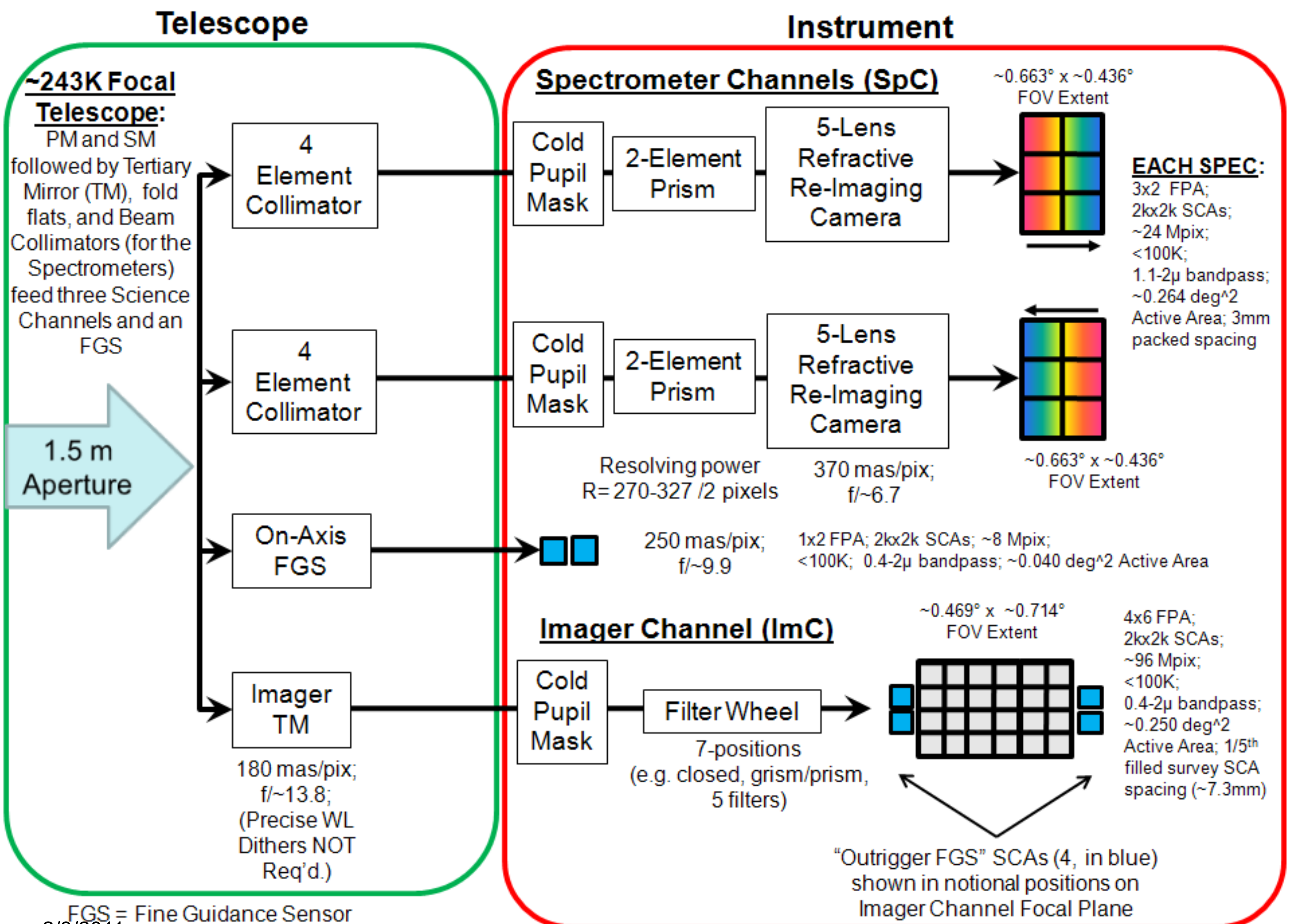


JWST HgCdTe array

JDEM-Omega Mission/Science Design Drivers

- Developed in an attempt to reduce cost from IDECS concept while still enabling 3 DE techniques
  - All NIR (focus on space-unique capabilities), reduced imager pixel scale to 0.18”/pixel
- 5 year mission, fully redundant spacecraft
- L2 orbit (minimal stray light, thermally stable)
- x10 improvement in determining cosmic equation of state
- x100 improvement in determining cosmic growth of structure (goal)
- BAO and SNe techniques are required while WL was made a goal due to uncertainty in capability of H2RG for shape measurements
  - BAO: ≥20,000deg^2, $0.7<z<2.0$, ≥100m galaxy redshifts
  - SNe: ≥1,500 SNe, $0.2<z<1.3$, ≥ 8 deg^2-yr field monitoring
  - WL: ≥10,000deg^2, >30 galaxies/arcmin^2, 1b galaxy images

Omega Payload Optical Block Diagram

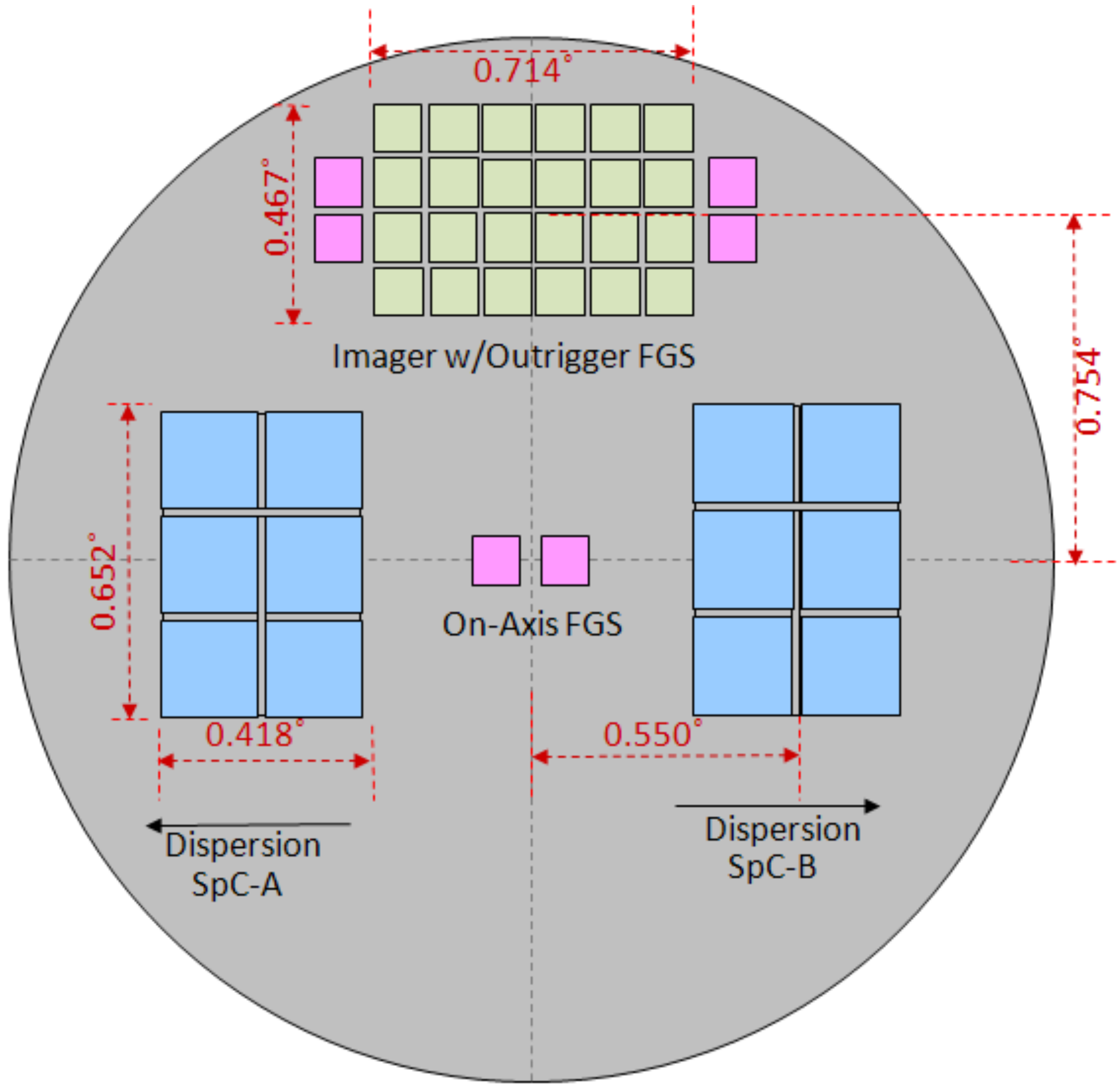


FGS = Fine Guidance Sensor

36 Science H2RGs

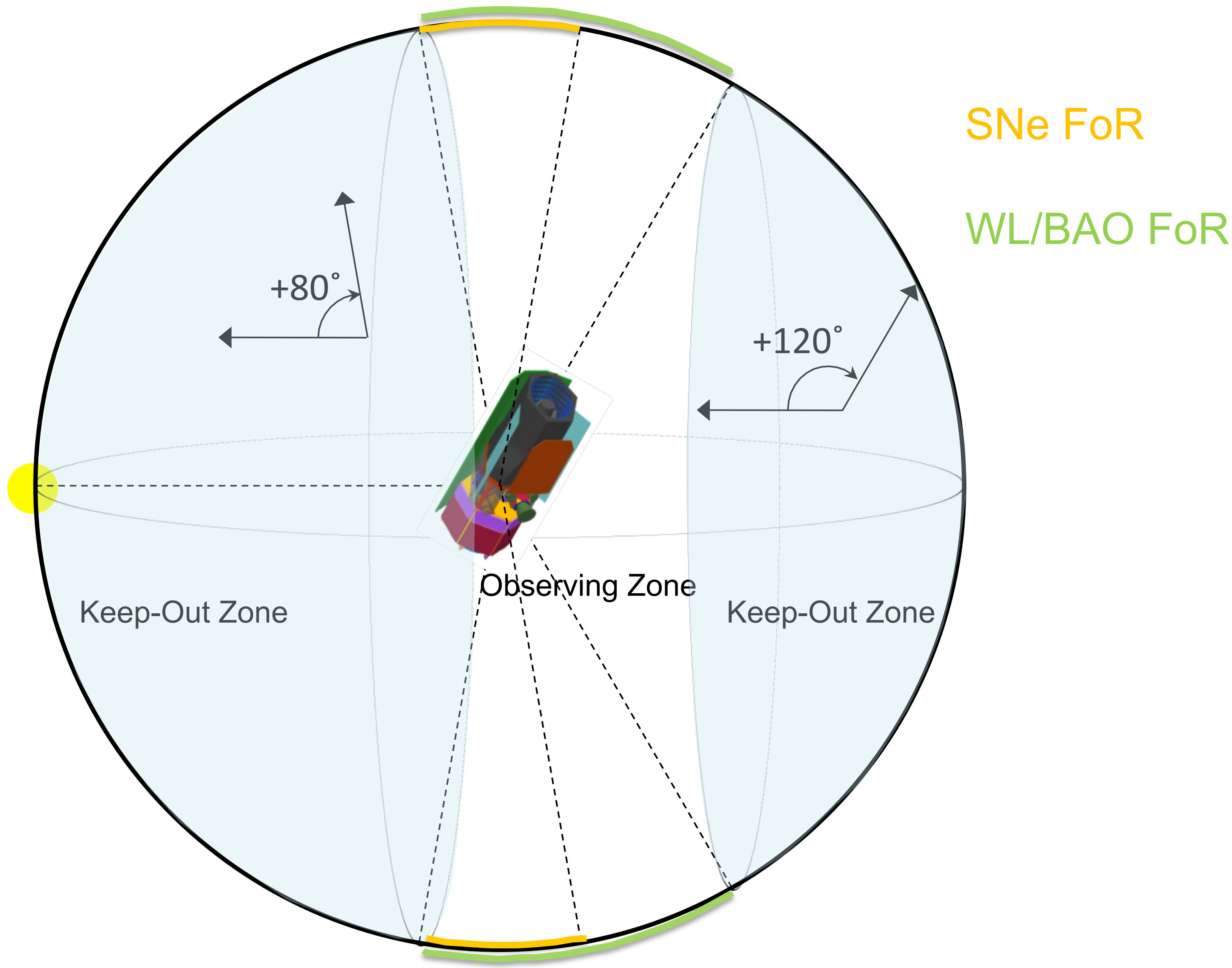
144Mpix

Omega Payload Fields of View (Looking Into Telescope)

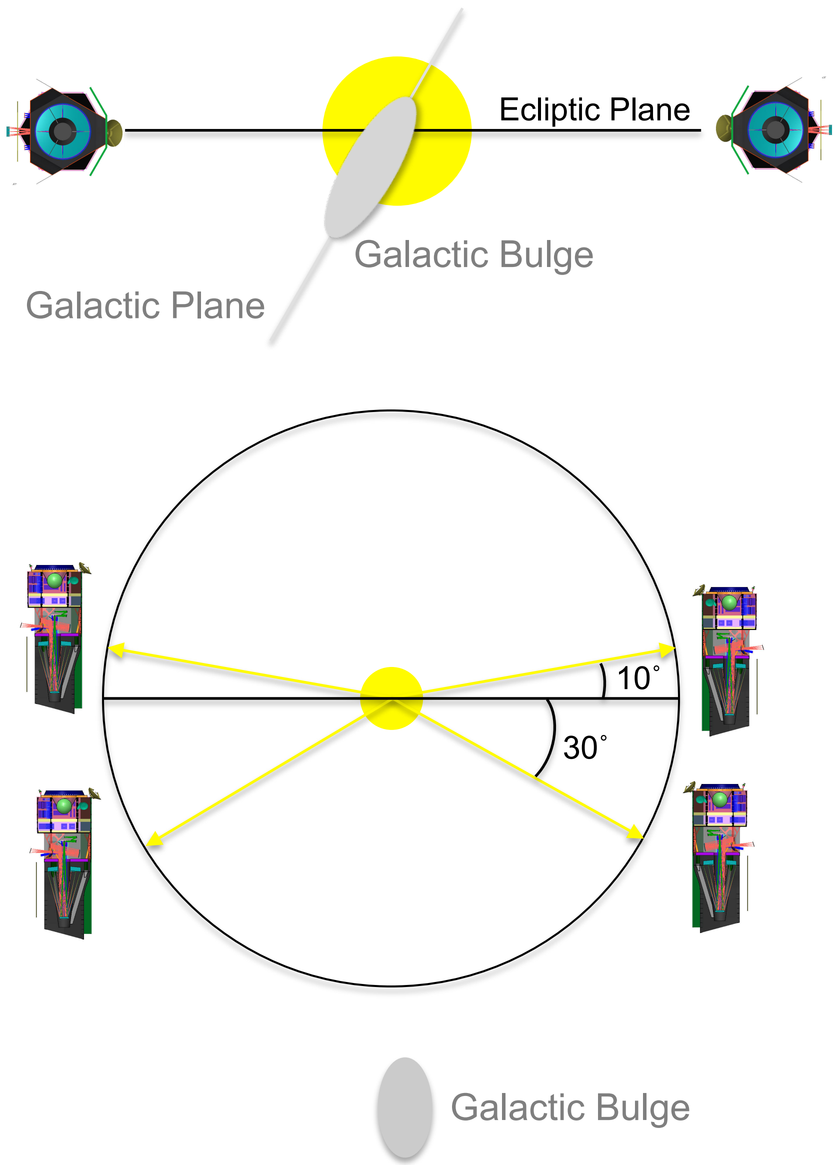


Sun Side

Payload Central Line of Sight Field of Regard



Omega Capability for Microlensing

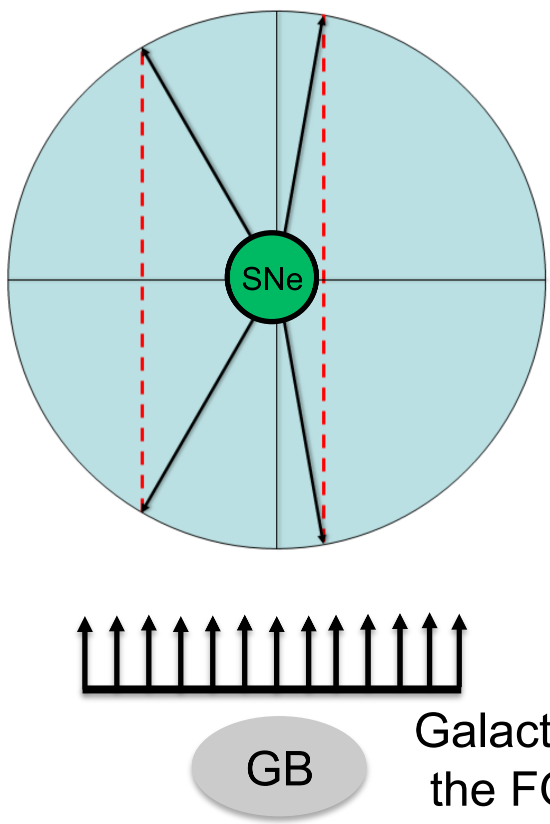


Looking down on the ecliptic plane, ~40 day seasons available to view the bulge

Omega Field of Regard and its Motion

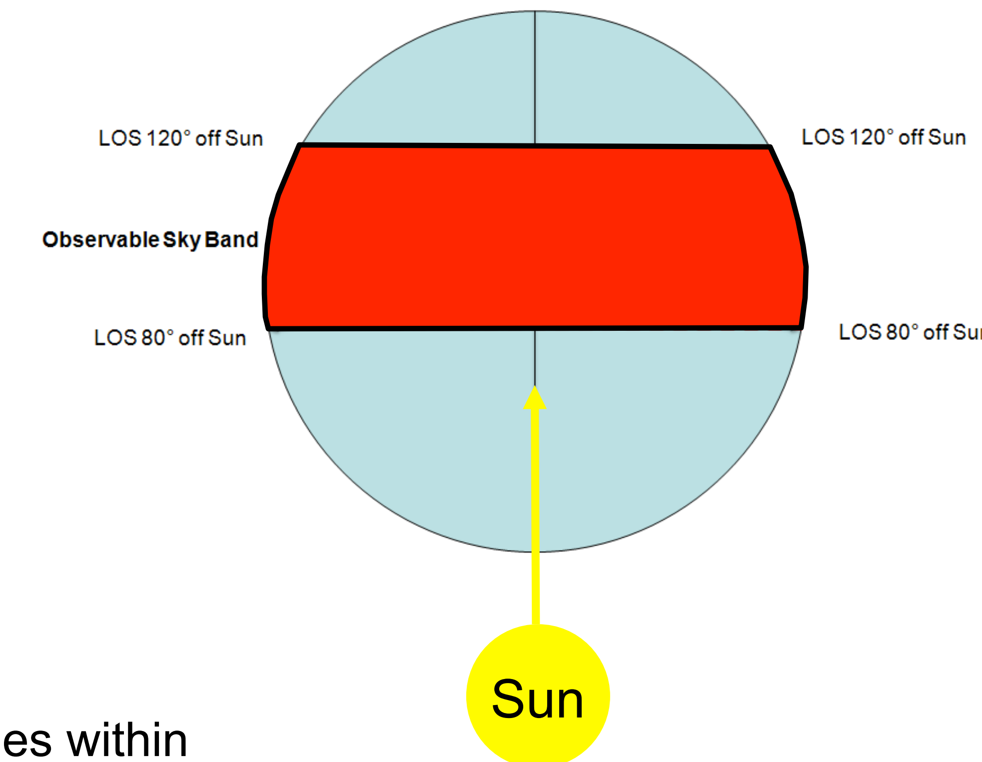
<Views looking normal to the ecliptic plane>

Orbital motion covers full sky twice/year; SNe fields at ecliptic poles always visible

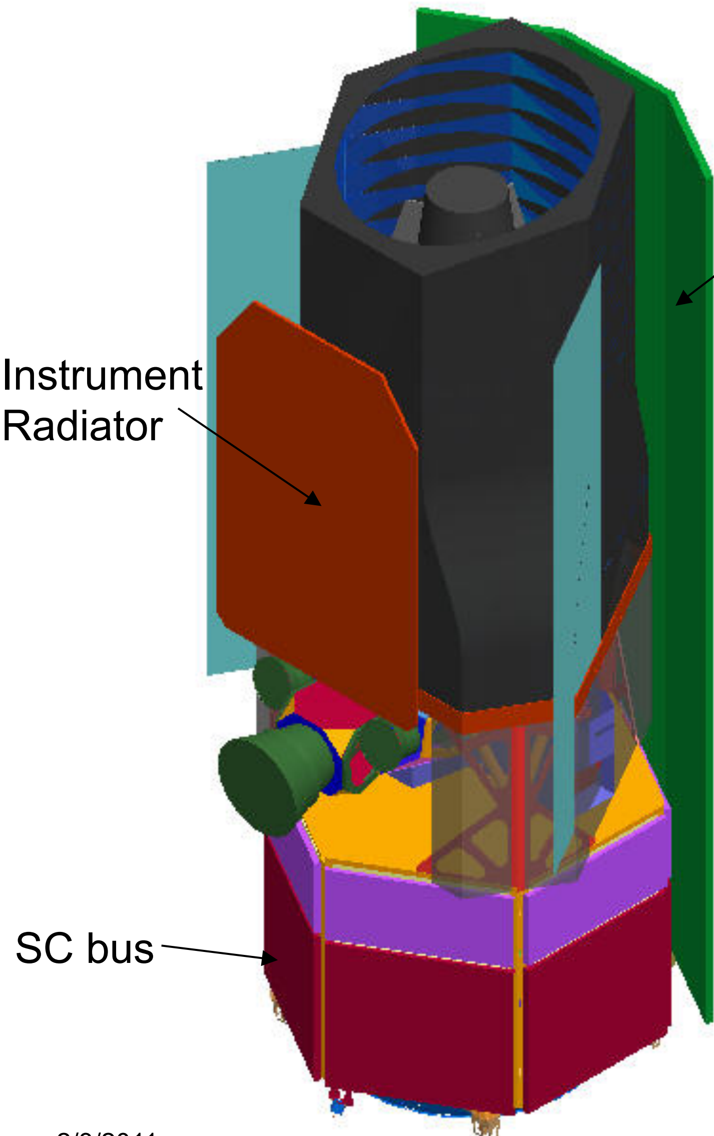


Galactic Bulge lies within the FOR for two 40-day seasons each year

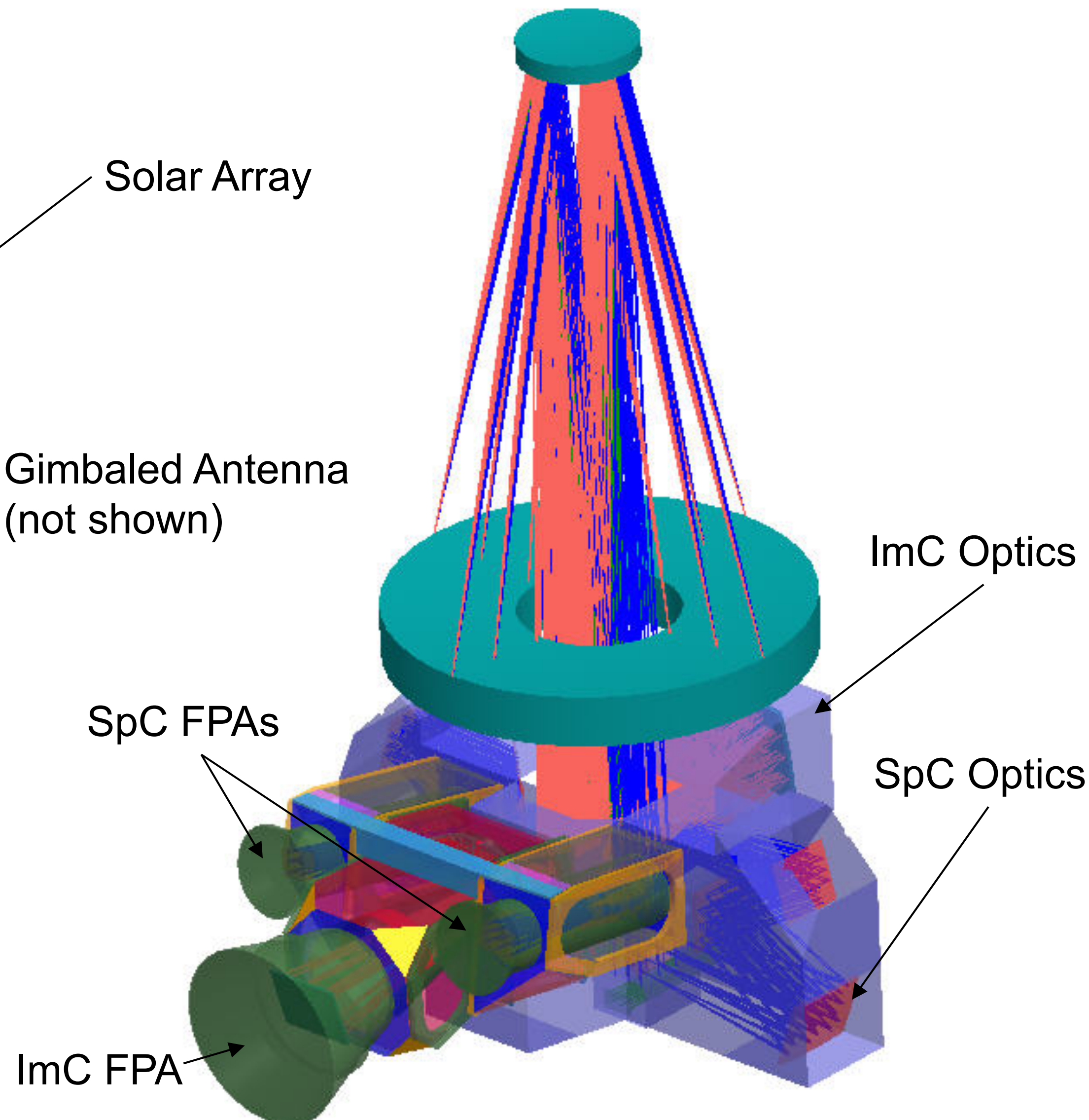
Instantaneous FOR is a 360° band with a width of 40° driven by Sun angles



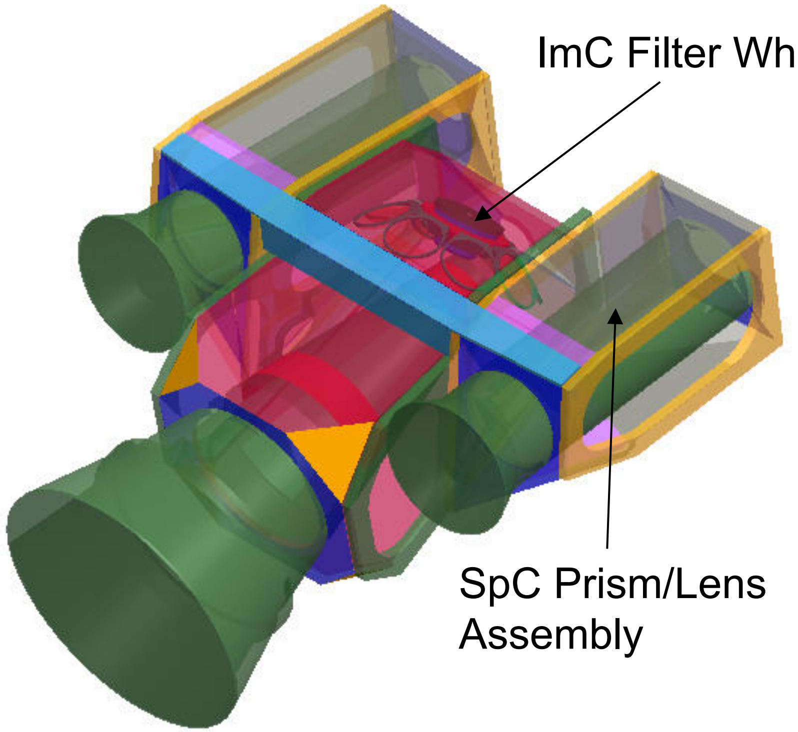
Omega Observatory Layout



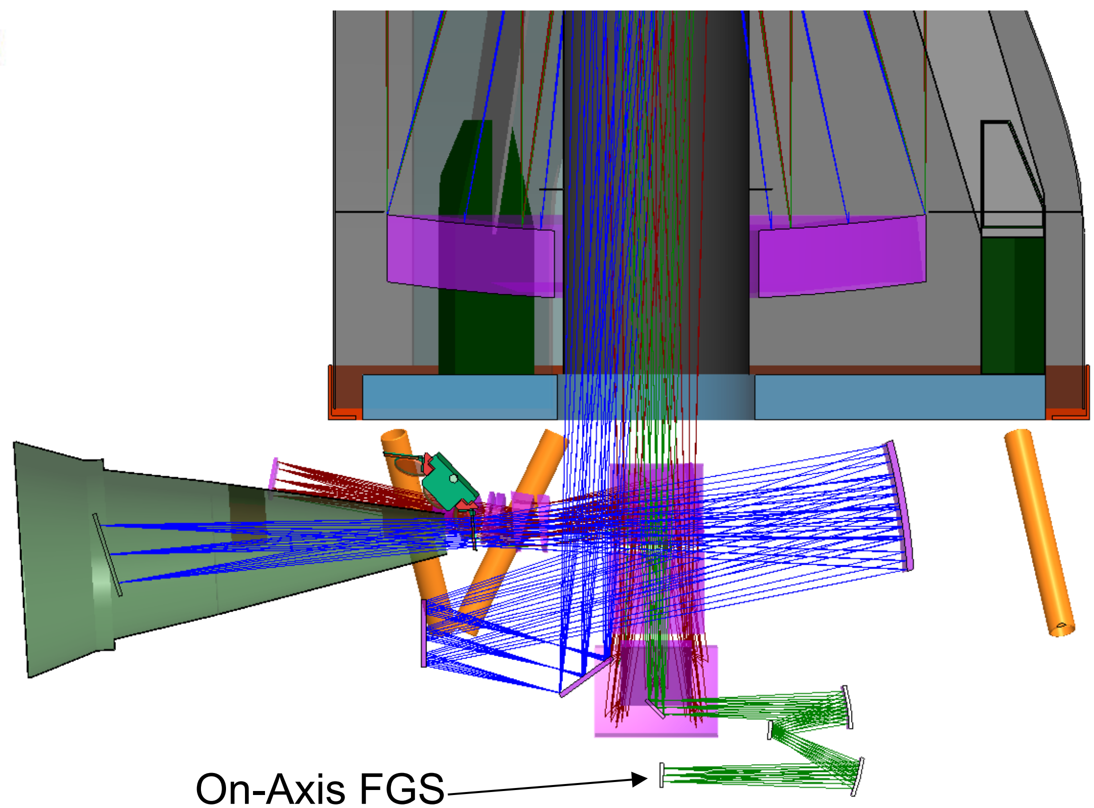
Gimbaled Antenna (not shown)



Omega Payload Layout



Ray Trace Colors
ImC = blue
SpC = maroon
FGS = green



Omega Science Returns

Observing Strategy	Return
• WL/BAO combined	3,300 deg^2/yr
• BAO only	6,900 deg^2/yr
• SNe	>1,500 SNe/yr

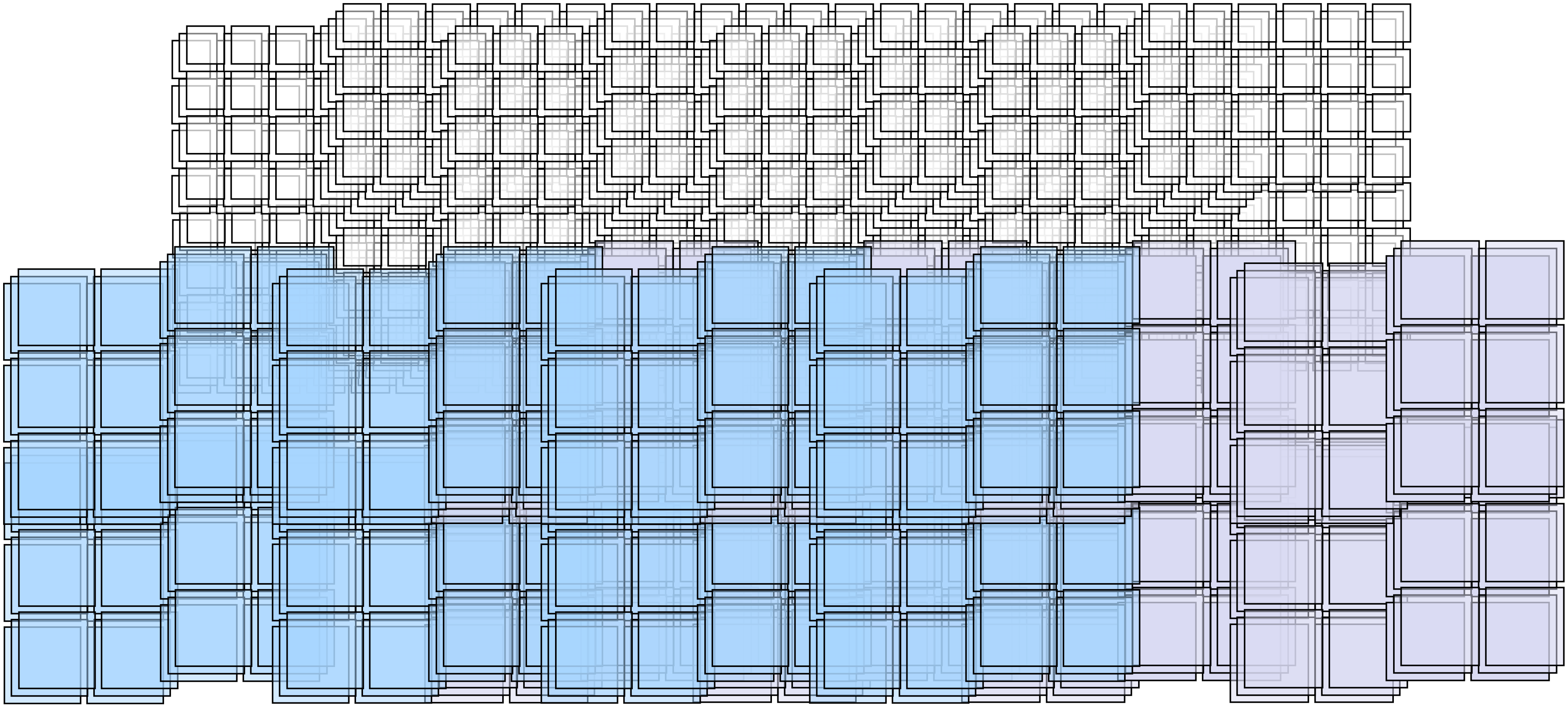
- Strawman Observing Plans
  - 3 years WL/BAO combined, 1 year BAO only and 1 year SNe
    - 9,900 deg^2 WL
    - 16,800 deg^2 BAO
    - 1,500 SNe
  - 2 years WL/BAO combined, 2 years BAO only and 1 year SNe
    - 6,600 deg^2 WL
    - 20,400 deg^2 BAO
    - 1,500 SNe

Basis for Estimates of BAO and WL/BAO Sky Coverage Rates Shown In Omega RFI#2

- BAO-only:
  - Observing Efficiency: 75%
  - Integration Time Required: 1800s of SpC time
  - Active SpC Area: 0.528 deg^2
- WL/BAO:
  - Observing Efficiency: 75%
  - Integration Time Required: 1800s of ImC time
  - Active ImC Area: 0.25 deg^2
- BAO and WL/BAO Coverages/Yr
  - BAO: 365 d/yr x 86400 s/d x 0.75 / 1800 s x 0.528 deg^2 = ~6900 deg^2/yr
  - WL/BAO: as above but with 0.25 deg^2 active area = ~3300 deg^2/yr
- The impact of integration time and filter variations over BAO ImC/SpC maps needs to be assessed in simulations; Mapping efficiencies and integration times are critical to coverage and need updating.

WL(/BAO) Smooth Filled Imaging and Rough Filled Spectroscopy **Animation**

Details on Mapping Rqts in Backup …

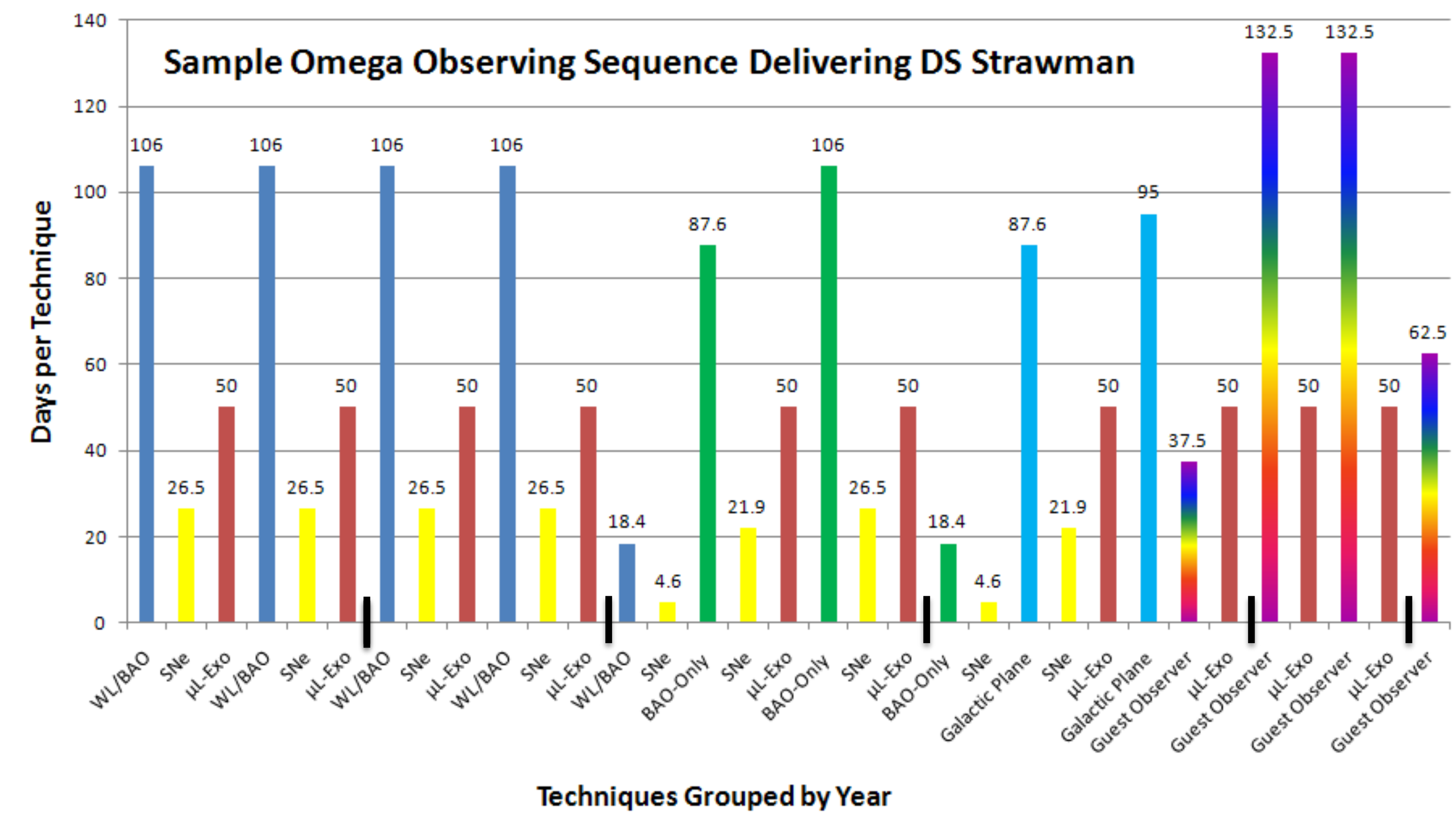


Animation Courtesy of Mark Melton

Omega's Capability to Deliver the Decadal Survey's Strawman 5 Yr Mission

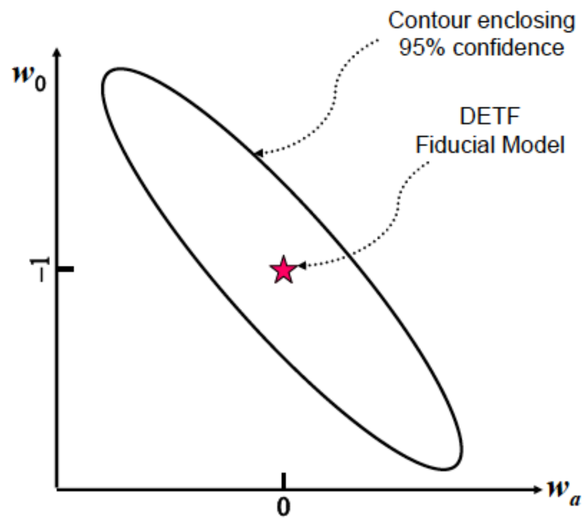
Technique	Strawman Allocation	Units	Omega Capability	Units	Omega Time Alloc (yrs)	Notes
WL	4000	deg^2	3300	deg^2/yr WL/BAO	1.21	Part of "2+" years allocated to Cosmic Acceleration; **Assumes Omega depth and integration times**; Smooth Filled Survey.
BAO	8000	deg^2	6900	deg^2/yr BAO-only	0.58	Part of "2+" years allocated to Cosmic Acceleration; **Assumes Omega depth and integration times**; Rough Filled Survey for BAO-only; Assumes 4K of BAO delivered during WL 4K survey, so time shown here is for 4K using BAO-only speed.
			3300	deg^2/yr WL/BAO	[1.21]	Time already covered by the 1.21 year WL/BAO survey.
SNe	~0.5	yr			0.5	The DS suggests interleaving SNe observations with the Weak Lensing/ galaxy survey to monitor high-redshift SNe (does "high-redshift" mean out to z=0.8?); Note that if Omega µL-Exo observations are made in two 50-day seasons each year for 5 years and are not interrupted, **the max SNe season is only ~132 days, a serious efficiency impact.**
µL-Exo	100	days/yr	100	days/yr (see notes)	1.37	100 days/yr required **for each of the 5 years**; **Not clear if the 100-day campaign each year can be split into two 50-day seasons, or what the impact would be of partial daily interruptions**; Omega can provide 80 days/yr, in two 40-day seasons 6 months apart, but this can be increased to two 50-day seasons with a relatively minor change to Omega's solar elevation requirements.
Galactic Plane	0.5	yr	0.5	yr	0.5	
Guest Observer	1	yr	1	yr	1	
Total					5.16	

Sample of a Possible Omega Implementation of the DS 5-Year Strawman Allocations



SNe is acquired for seven 132 contiguous-day seasons, getting 1/5th of each day;
No additional SNe time is allocated to compensate for the µL-Exo interruptions;
Order of WL/BAO, BAO, and Galactic Plane Surveys is arbitrary.

DETF Figure of Merit



The DETF figure of merit is defined as the reciprocal of the area of the error ellipse in the w_0–w_a *plane that encloses the 95% C.L. contour. (We show in the Technical Appendix that the area enclosed in the* w_0–w_a *plane is the same as the area enclosed in the* w_p–w_a *plane.)*

$$w = w_o + w_a\,(1+a)$$

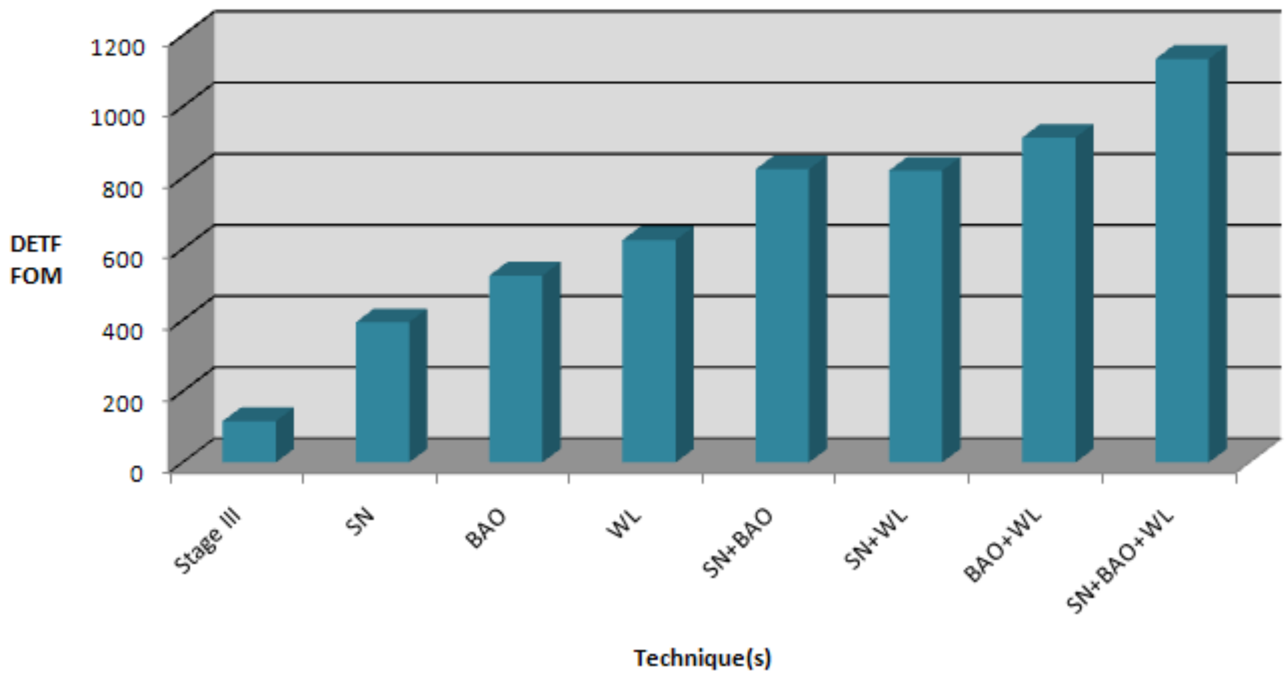
where:

$a = 1 / (1+z)$ scale factor of universe

w = pressure / density

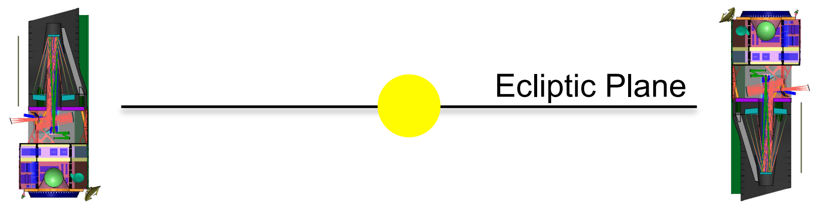
JDEM FoM

- Key dark energy FoMs defined by DETF and FoMSWG committees
  - **DETF FoM** measures dark energy equation of state
  - **Gamma FoM** measures growth of structure
- DETF FoM grows as techniques are added

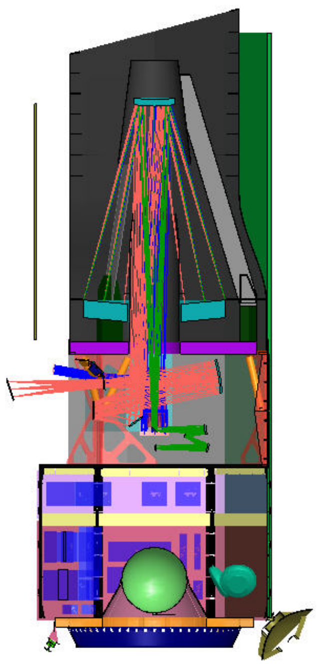


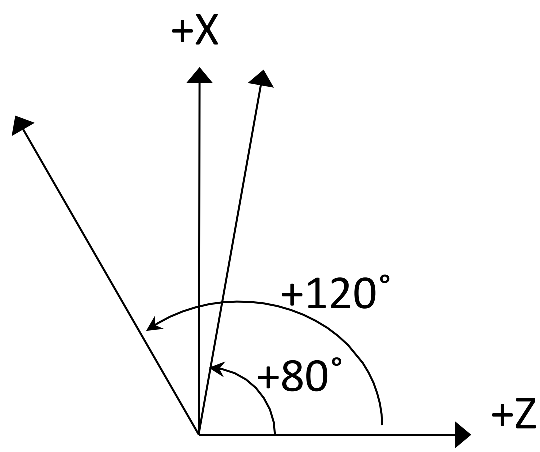
Backup Slides

Omega BAO/WL Fields of Regard



Observatory can observe either the northern or southern sky

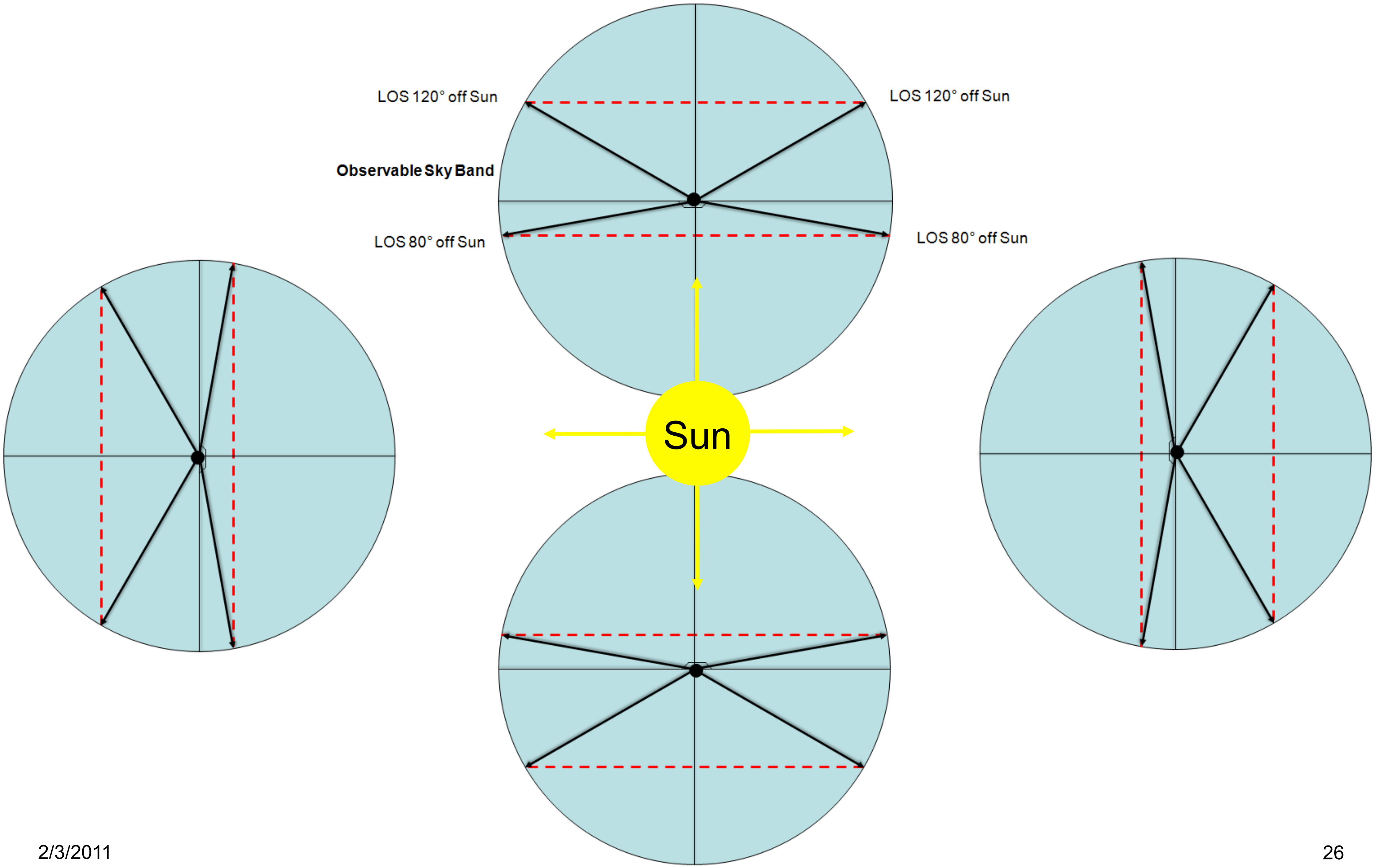




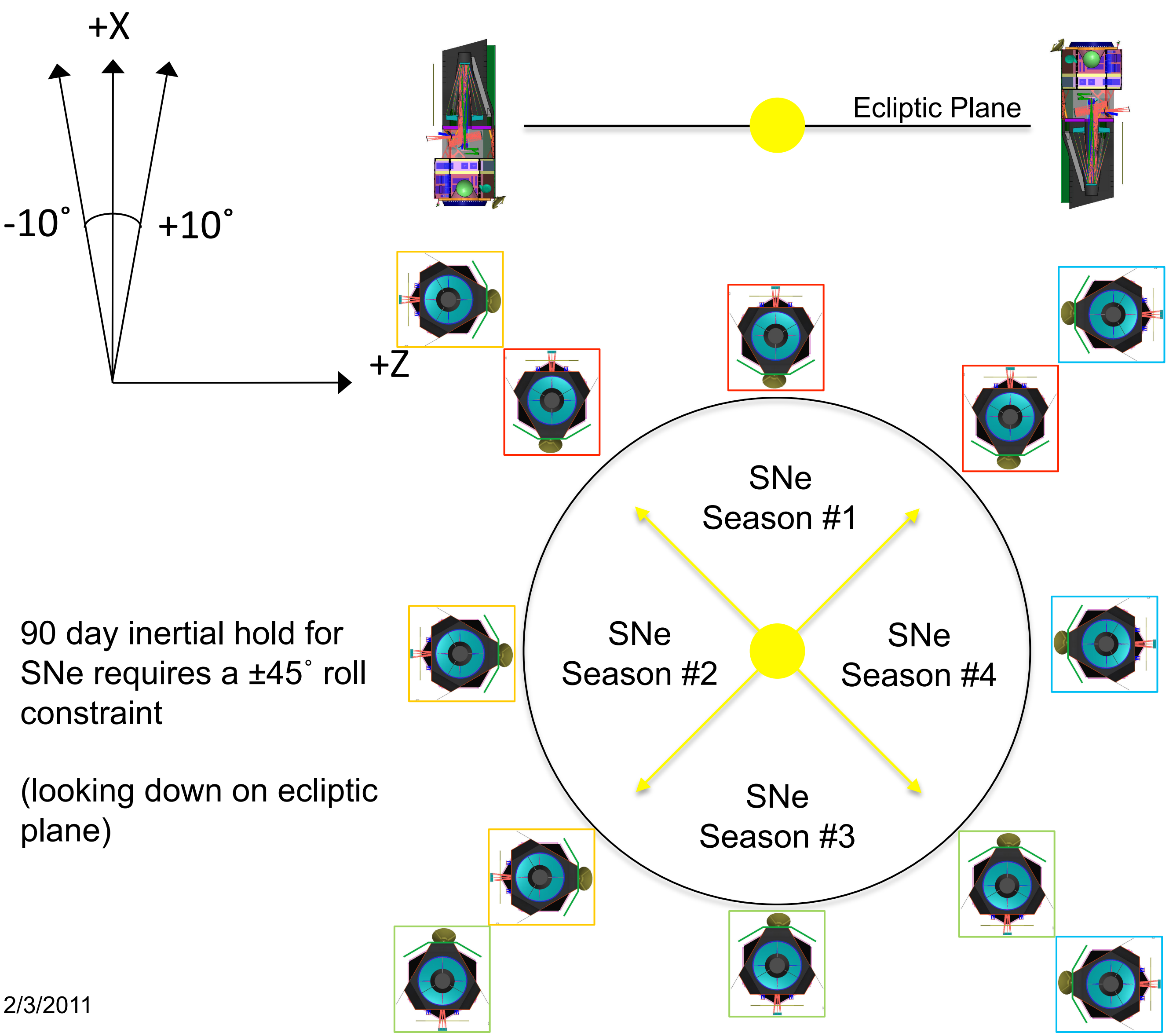
Roll about +X constrained to +/- 10˚

No constraint on yaw about +Z axis

Payload Central Line of Sight Field of Regard



Omega SNe Field of Regard



Observatory observes a 10˚ radius circle about either the northern or southern pole

90 day inertial hold for SNe requires a ±45˚ roll constraint

(looking down on ecliptic plane)

Pointing Requirements

- Pointing Requirements
  - Coarse Pointing Accuracy: 3 arcsecs RMS/axis
  - Offset Pointing Accuracy (for small dithers): 25 milliarcsecs RMS/axis
  - Pointing Stability (Jitter): 40 milliarcsecs RMS/axis
  - Pointing Knowledge: 4 milliarcsecs RMS/axis

Basis for Estimates of SNe-Ia Characterization Rates In Omega RFI#2

- Deg^2-Years of SNe Monitoring (5 yrs) : 8.3 (0.25 * 7 * 0.95 * 5)
  - Field Active Area: 0.25 deg^2
  - Fields Monitored on 5-day Cadence for 5 years: 7 (1.75 deg^2 total)
  - (set by 4800s/4800s Imaging / Spectroscopy time, 20% SNe time per day, and 80% SNe observing efficiency)
  - Area loss due to non-square: 1-(6.66/7) = 5% (6 fields square, 2/3 of 7th)
- Basis for 4800s Imaging and 4800s Spectroscopy Time:
  - ImC S/N≥25-30 at peak at z=1.3; Prism S/N≥3 per 10A at 0.58μm (rest)
  - 5 filters (0.4-1.7μm) and an R-75 prism on each field;
  - z-goal 0.2-1.3 (Spec time good to z~0.9; image time realloc gets to z~1.1)
- SNe Return: (using Dahlen et al 2008)
  - For a z-range of 0.2-1.3, 8.3 deg^2-years will detect ~1500 SNe-Ia;
  - Per above, z-range likely only 0.2-1.1 for time allocated and fields viewed;
  - No layering in Omega to create low, mid, high z fields to balance yields.

Some Issues that Impact Delivery of the DS Strawman

- During BAO mapping, does DS require Smooth-Filled imaging?
- What is the impact on the BAO Science Catalog of variations in depth and dispersions across the area covered?
- Ratio of WL and BAO integration times will be key to WL/BAO survey, and Omega integration times need updating;
- Mapping Efficiencies need updating, with settling times being a key consideration;
- Two 50-day µL-Exo seasons per year for 5 years will limit SNe seasons to no more than 132 days, and to some extent will notch maps created for other Science techniques;
- Change in z-range for DS SNe (DS z=0.8 vs Omega z=1.2) will impact field monitoring coverage/depth trade.

Omega Ops Concept Considerations for Delivering the DS Strawman 5 Yr Mission

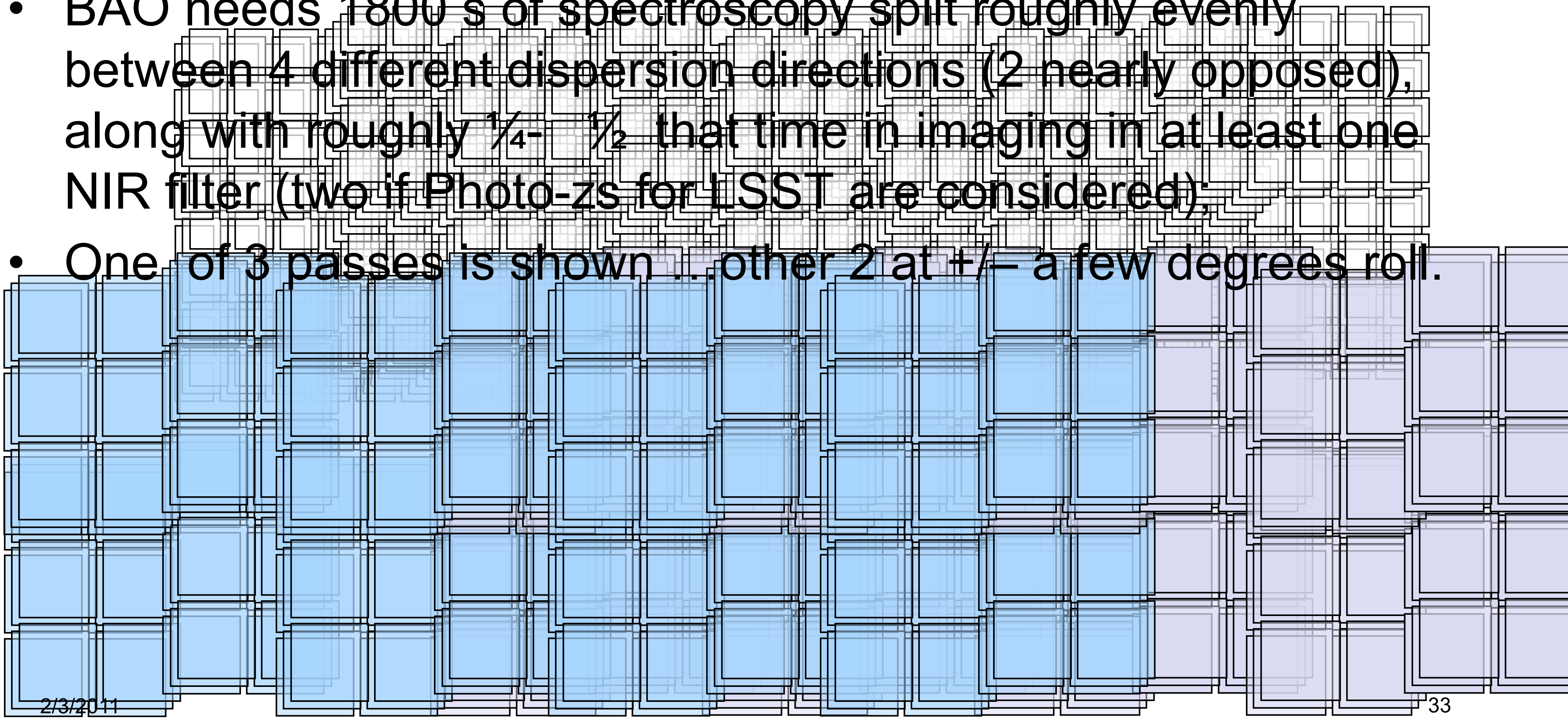
Technique	Field Location Thoughts for Decadal Strawman	Interruption Tolerance	Constraints and Other Notes
WL(/BAO) Survey	**A Skull Cap centered on the South Ecliptic Pole** would provide LSST field overlap for Ph-zs and low-hanging low-zodi fruit. The Cap can, less µL-Exo interruptions, be 360° after 6 months or 1 year; Either WL/BAO or BAO-only could be done first.	Tolerated daily if needed ...	There are many possibilities, but let's assume that we stay with the Omega allocation of 1/5th of each WL/BAO day to SNe. See SNe notes for impact of µL-Exo twice-yearly interruptions.
BAO-only Survey	**Area adjacent to the WL/BAO skull cap** would be logical, perhaps a ring at lower latitudes; Either WL/BAO or BAO-only	Tolerated daily if needed ...	Ditto to the above for the BAO-only observations.
SNe Survey	**7 fields, 0.25 deg^2 each, was the Omega baseline,** based on **1/5 of each days wall clock time and a 5-day observing cadence**; a South Pole field would make sense given the WL and BAO survey locations; ~square field pattern allows 90-day inertial holds with continuous monitoring; **not reoptimized for DS z=0.8 max guideline**.	Tolerated but complete field monitoring every 5 days ...	Cannot interleave within µL-Exo surveys, and since µL-Exo surveys are required twice a year, SNe seasons are limited to 132 days (see below); Trade on how much time to allocate to SNe on a given day, up to 100%.
µL-Exo Survey	**The field location is the Galactic Bulge.**	Interruptions not allowed ...	If the µL-Exo survey is executed twice a year for 50 days for all 5 years, then **the longest contiguous SNe survey that can be executed is ~132 days.**
Galactic Plane Survey	**80°-100° of the Galactic Plane is in the FOR each day**, in two 40-50 degree segments centered 180 degrees apart (100° if µL-Exo FOR extension). Other than that, TBD.	TBD	TBD
Guest Observer Surveys	**TBD**	TBD	TBD

BAO-Only Mapping Efficiency Sample Estimate Reference

Science Mapping or Monitoring Efficiency Loss Considerations	Hours Lost/Yr	Time Allocs (s)	Efficiency Factor	Notes
No Science Ops Possible	181	---	0.979	e.g. Safehold, Station Keeping, Momentum Unloads, Comm Interruptions, Major Slews to Field Areas (and subsequent thermal/dynamic settling), etc.
Science Ops Possible but FOR Fixed or Limited	104	---	0.988	e.g. Comm if no gimballed antenna, Calibration time, other?
Repeated Losses Between Exposures	---	---	0.841	
Integration Time btwn Slews/Settles	---	225	---	A sample value for Omega BAO-only exposures.
Slew Time	---	25	---	Will vary with the size of the slew, from dithers to a degree or so, and the precsion of the pointing req'd.
Settle Time	---	15	---	Will vary with precision of the settle that is req'd.
Reset(s) Time	---	2.6		2.6s accounts for two frames.
Efficiency of Overlapping of Exposures to Deal with SCA gaps	---	---	1	This factor is not considered in this rollup, so set to 1.
Efficiency of Overlapping of Exposures to Deal with Field-to-Field gaps	---	---	1	This factor is not considered in this rollup, so set to 1.
Science Mapping Efficiency Rollup	---	---	**0.814**	**Sample for above assumptions**

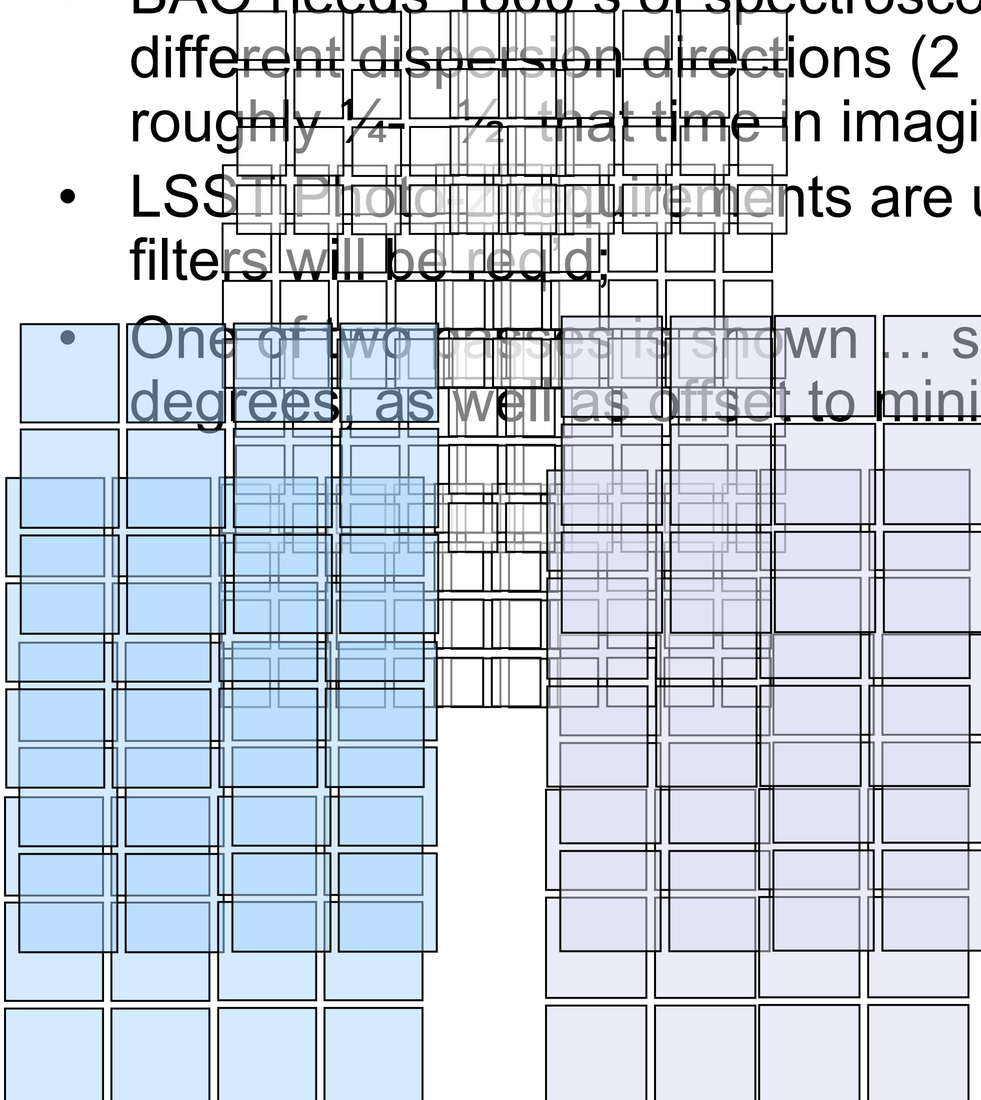
WL(/BAO) Smooth Filled Imaging Survey Overview: 3300 deg^2/yr

- WL needs 600s Imaging w/4 random dithers in each of 3 filters; no gaps allowed, so each filter can be at a different roll angle, as needed for the BAO survey;
- BAO needs 1800 s of spectroscopy split roughly evenly between 4 different dispersion directions (2 nearly opposed), along with roughly ¼- ½ that time in imaging in at least one NIR filter (two if Photo-zs for LSST are considered);
- One of 3 passes is shown …other 2 at +/– a few degrees roll.



BAO-Only (+LSST Ph-zs) Rough Filled ImC/SpC Survey Overview: 6900 deg^2/yr

- BAO needs 1800 s of spectroscopy split ~evenly between 4 different dispersion directions (2 nearly opposed), along with roughly ¼ – ½ that time in imaging in at least one NIR filter;
- LSST Photo-Z requirements are uncertain, but maps in two NIR filters will be req'd;
- One of two passes is shown … second would be rolled a few degrees, as well as offset to minimize ImC SCA gaps.



Omega SNe-Ia Field Monitoring Overview

- 7 fields, 0.25 deg^2 each, are monitored on a 5-day cadence;
- 2x2 or 3x3 (tbd) precise dithers are used for each observation (not shown in animation);
- Each of 6 filter wheel settings (5 filters and one prism) is used once every 5 days;
- Field revisits are inertially held for ~90 days